

# Effects of the February 27, 2010 Chilean Tsunami on the Harbors, Ports, and the Maritime Community in California\*

\* With comparison to preliminary evaluation of March 11, 2011 tsunami



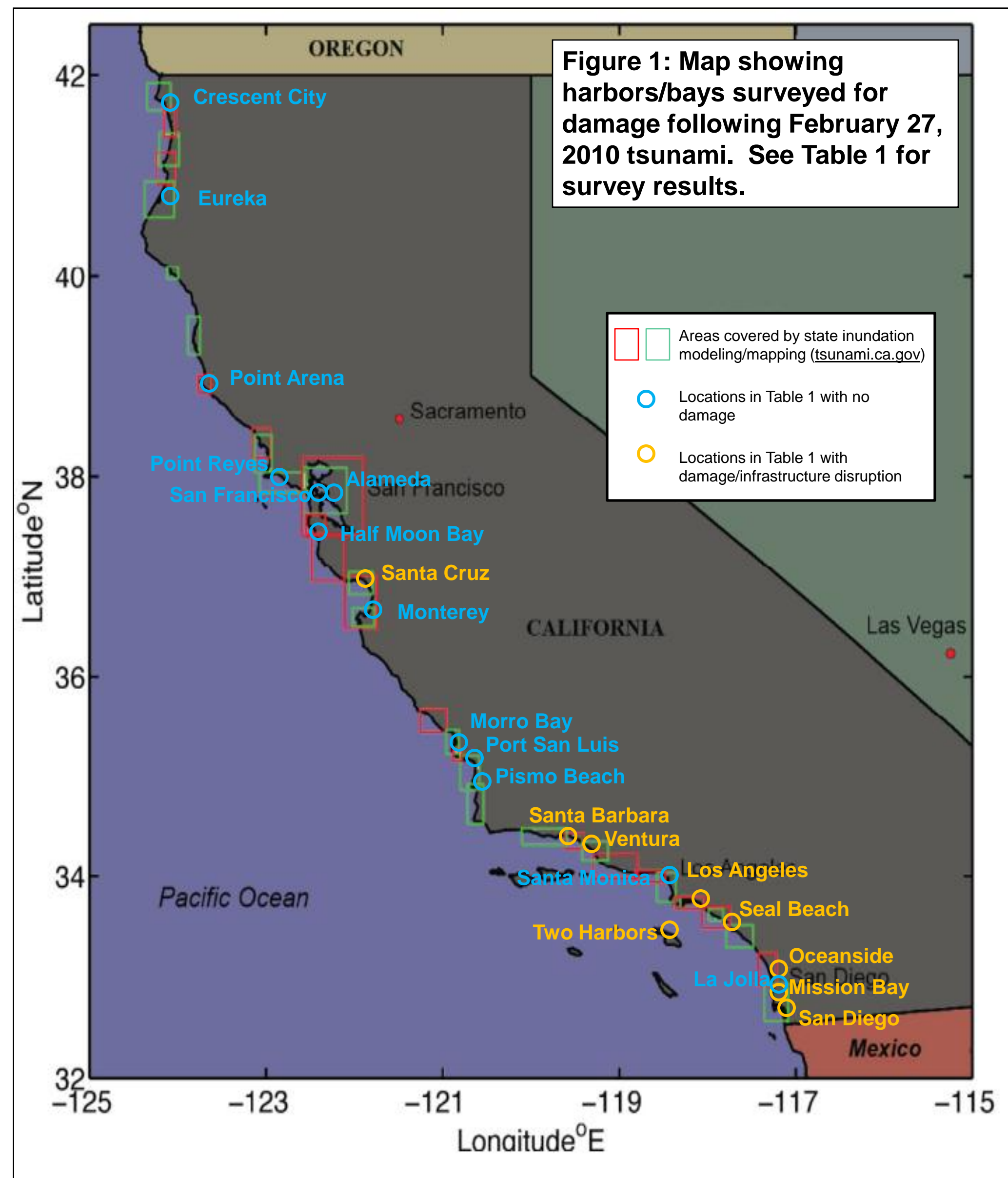
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  - 8 U.S. Geological Survey – Santa Cruz
- For more information on this work, visit [www.tsunami.ca.gov](http://www.tsunami.ca.gov)

**ABSTRACT:** At 12:02pm (PST) on February 27<sup>th</sup>, 2010, the tsunami generated by a magnitude 8.8 earthquake originating off the coast of Chile, first arrived in southern California. The West Coast/Alaska Tsunami Warning Center forecasted tsunami amplitudes ranging from 0.18 to 1.43 meters with the highest amplitudes predicted for central California and areas to the south (Figure 1; Table 1 summarizes the surveyed locations and damage). The highest recorded amplitudes occurred from one to six hours after the first wave arrival, with a maximum statewide tide gauge reading of 0.91 meters in Santa Barbara (Figure 2) and the maximum observed amplitude of 1.2 meters at Pismo Beach and in San Diego Bay. Surging water and rapid tidal fluctuations in many harbors and bays produced strong ebb and flood currents up to 15 knots at some locations. Currents in excess of 8 knots are known to cause damage to piers and docks. These conditions caused minor to moderate damage to docks, boats, and harbor infrastructure in at least a dozen locations statewide. The strongest currents and most severe damage occurred at Shelter Island (San Diego), Mission Bay, and Ventura Harbor. The strongest tsunami activity took place primarily under low-tide conditions, likely reducing the impact of the tsunami on beaches and in harbors and bays. While overall damage estimates are still being collected, initial estimates indicate that damage costs could approach \$3-million within California; Tsunami current data is being compiled from instrumentation, video footage, and eye-witness observations in order to help validate/calibrate numerical modeling estimates. Based on feedback from post-event surveys, the State of California is developing tsunami hazard map products for areas within harbors and offshore to help the marine community prepare for future tsunamis. The state is also creating pre- and post-tsunami field teams comprised of scientists and engineers to better record the effects of tsunamis and to provide assistance to state and local emergency planners before, during, and after an event.

More recently, on March 11, 2011, another tsunami generated from a magnitude 9.0 earthquake near Japan caused significantly more damage in California. Based on inspections by the newly formed tsunami field teams and a preliminary analysis by CGS, moderate to strong currents were observed in all coastal harbors and marinas in California, leaving at least two dozen marine facilities with damage (Wilson and others, 2011; see Table 1). The most significant damage was experienced in Crescent City's small boat basin and Santa Cruz Harbor. Official estimates of damage by the State of California and FEMA are over \$48 million, with other "non-official" estimates adding tens of millions of dollars to that total.

Due to the significance of the March 11, 2011 event to the state maritime community, we have provided photos and information for comparison to the February 27, 2010 tsunami. The impacts, issues, and lessons learned within the maritime community reflect both of these events.



## February 27, 2010

### M8.8 Chile

Strong currents near entrance to Crescent City Small Boat Harbor make navigation difficult.



Boats brake loose in upper portion of Santa Cruz Harbor.



Large tidal fluctuations cause severe damage to 20 docks in The Keys section of Ventura Harbor.



Strong currents result in damage to dock in north Shelter Island, San Diego Bay.



## March 11, 2011

### M9.0 Japan

Extreme currents within Crescent City Small Boat Harbor destroyed docks and sunk boats.



One meter bore in upper Santa Cruz Harbor causes damage to docks and boats.



Strong surges overtop docks in Ventura Harbor. Dock damage occurs 15 hours after first arrival.



Boat sinks and damages dock due to strong drag in south Shelter Island, San Diego Bay.



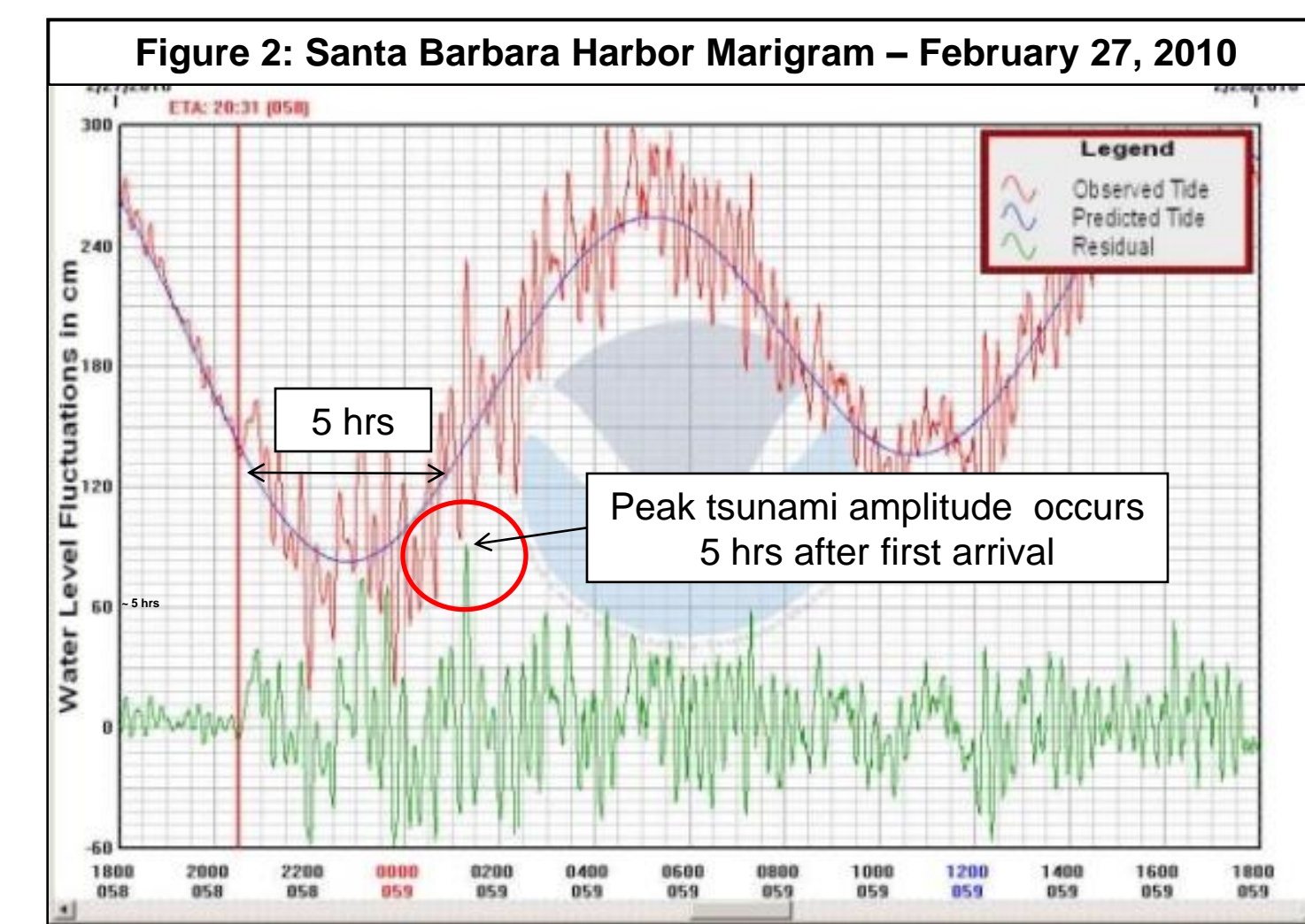
**Table 1:** Recorded and observed measurements and damage estimates in California from the February 27, 2010 and March 11, 2011 tsunamis. Current speed estimates may be overvalued because of inexperience of observers. Blank cells indicate that data was not collected for those locations; they do not represent zero values. Red boxes associated with photos to the left.

Harbors, Ports, Bays, and Docks Surveyed (from north to south)	Feb. 27, 2010 First Arrival Times		Maximum Tsunami Amplitudes				Estimated Maximum Current Speeds (knots)		Reported Damage or Other Effects from Tsunami (NDR = no damage reported)	
	Forecasted (PDT)	Observed Tide Gauges (PDT)	Feb. 27, 2010 Forecasted (meters)	Feb. 27, 2010 Observed Tide Gauges (meters)	Feb. 27, 2010 Estimated By Others (meters)	March 11, 2011 Observed or Estimated (meters)	Feb. 27, 2010	March 11, 2011	Feb. 27, 2010	March 11, 2011
Crescent City	1340	1346	0.61	0.64		2.47		20-25	NDR	Near complete destruction of small boat harbor (\$20M)
Eureka	1336	1333	0.2	0.23		0.97			NDR	NDR
Noyo River						0.8-1.0		15-20	NDR	Major damage to docks/boats (\$4M)
Arena Cove	1248	1304	0.49	0.39		1.74			NDR	NDR
Point Reyes	1259	1259	0.46			1.35			NDR	NDR
Martinez						0.06			NDR	NDR
Oakland						0.51		4-6	NDR	Minor damage at nearby Berkeley Marina
Alameda	1344	1345	0.18	0.12		0.51		4-6	NDR	NDR
San Francisco	1320	1326	0.22	0.32		0.62		7	NDR	NDR
Half Moon Bay			0.96		0.6	0.7	7-10	7-15	NDR	NDR
Santa Cruz			0.51		0.9	1.6-1.9	8-10	20-25	Minor damage to boats and harbor infrastructure	Multiple docks destroyed, 20 boats sunk (\$28M)
Moss Landing					0.3	2		15-25	NDR	200 piles damaged (\$1.8M)
Monterey	1231	1243	0.45	0.36	0.3	0.7	2	6-7	NDR	NDR
Morro Bay			0.82		0.5	1.6	4-6	15-20	NDR	Damage to several docks and boats (\$500k)
Port San Luis			0.84		0.8	2.02		5	NDR	NDR
Pismo Beach			1.43		0.9-1.2	0.7-1.0			NDR	NDR
Santa Barbara	1230	1231	0.75	0.91		1.02	8-10	10-20	Minor damage to dredging equipment	Damage to barges and boats (\$70k)
Ventura					0.6-0.9	1.3	12-15	10-15	Over 20 docks damaged; buoys moved	Damage to dock and number of boats (\$150k)
Oxnard					1.0	0.9-1.2	2-3	8-10	Dock damage from large boat wake	Minor damage to docks
Port Hueneme						0.5-0.7			NDR	NDR
Santa Monica	1225	1225	1.18	0.64		0.85			NDR	NDR
Marina Del Rey					0.1	0.9-1.0		6-8	Minor damage to dock	Minor damage to docks; dingies sunk
Two Harbors/Catalina						0.6-0.9		12-15	Minor damage to several docks	Damage to several docks and 10 boats
Los Angeles	1215	1215	0.77	0.42		0.49	4-6		Minor damage to docks and marine infrastructure	Minor damage to docks and boats
Long Beach								10-12	NDR	Minor damage to docks and boats
Sunset						0.3-0.6			NDR	NDR
Huntington						0.72	5-8	8-10	NDR	Boat pulled off mooring
Newport					0.5	0.3	8-10	5	NDR	NDR
Dana Point						0.5-0.7	0.6	10-12	10-15	Bait barge severed
Oceanside					0.6	0.5	5-10	4-6	Minor dock damage; several buoys carried to sea; boat trailer swamped	NDR
La Jolla	1202	1202	0.84	0.60		0.39			NDR	NDR
Mission Bay							8-10	6-8	Small sailboat swamped trying to leave harbor; buoys moved	Dock destroyed, 13 boats damaged (\$136k)
North Shelter Island, San Diego Bay						0.9-1.2	0.3	12-15	7-8	NDR to north Shelter Island; however, a boat sunk and there was damage to dock in south Shelter Island
Cabrillo Island, San Diego Bay						0.3-0.5			NDR	NDR
Marine Corps RD, San Diego Bay						0.6			NDR	NDR
Navy Pier, San Diego Bay	1204	1208	0.27	0.40	0.6	0.63			NDR	NDR
Marriot Marina, San Diego Bay						0.3-0.6	0.6		NDR	Wake buoy moved
National City, San Diego Bay									NDR	NDR

## Issues within the Maritime Community:

The two events caused a number of problems for the maritime/boating community:

- Harbor masters had to make quick, critical decisions about evacuations within the harbor. Although life-safety was the primary concern, the uncertainty about recommending evacuation of boats out to sea is an important consideration.
- Boaters, especially recreational boaters, had to make under-informed decisions about whether or not to take their boats offshore prior to the arrival of the tsunami. Most did not plan ahead for this contingency so they had to leave their boats in harbor. In most cases, leaving their boats docked was the right thing to do for these particular tsunamis.
- Most recreational boaters don't understand that strong tsunami activity can last a long time, more than 8 hours during the February 27, 2010 tsunami and 24 hours in some places in California during the March 11, 2011 event. For boaters that did go offshore, many did not have supplies or the experience to stay offshore until the dangerous tsunami activity was over.
- Many recreational boaters that tried to return to the harbors during the tsunami had difficulty doing so and caused problems for harbor patrol personnel. In several cases, these boats caused damage to other boats and docks, and injury to harbor personnel when trying to dock.



## Acknowledgements and References

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Other tsunami information for California: [www.tsunami.ca.gov](http://www.tsunami.ca.gov)

## Tsunami Effects in California

Information about the effects of the tsunami were available from eyewitness accounts, questionnaires, on-line articles and videos, and field measurements and interviews by several of the co-authors. Table 1 shows WCATWC tsunami forecast amplitude and arrival time estimates, measured data from tide gauges, and observations from various sources (the data from the March 11, 2011 tsunami is still being collected and therefore should be considered preliminary).

A summary of the effects from the February 27, 2010 event are presented below (again, effects from March 11, 2011 still being collected):

- Large tidal fluctuations (initially at low tide)**
  - Maximum 2m to 2.5m (peak to trough) observed on beaches in Pismo; drawdown dramatic in some places.
  - Peak amplitude on West Coast 0.91m measured in Santa Barbara Harbor (Figure 2); note peak occurs 5 hrs after first arrival.
- Strong currents**
  - Strongest at harbor entrances and within narrow channels.
  - Up to 15 knots in several southern California harbors.
- Significant erosion/scour**
  - Moderate along beaches and river mouths.
  - Ventura Harbor reported dredging savings from scour (approx. \$100k).
- Damage**
  - Docks, boats, harbor infrastructure, minor flooding; approx. \$3M statewide.
  - Harbors: Santa Cruz, Santa Barbara, Ventura, Los Angeles, Two Harbors/Catalina, Dana Point, Mission Bay, and San Diego with flooding in Seal Beach following day.
- Extended tsunami activity (nearly 24 hrs: 12:02 2/27 to morning of 2/28)**
  - Strong surges continued into evening, observed in Mission Bay and Morro Bay.
  - Following morning, storm surge plus tsunami activity produced flooding at Huntington Beach.

## Lessons Learned - Harbors

The majority of people in the boating community needed further education and guidance about what should have been done before and during a tsunami. Maritime guidance should include some of the following "lessons learned" from the February 27, 2010 event:

- Avoid outside sources for alert information or actions**
  - Some areas reported hearing alert level changed to "Warning" when it had not; others called off response too early because they thought it safe
  - Official source is NOAA/National Weather Service, West Coast/Alaska Tsunami Warning Center and local gov. authorities via the local/regional media
- Don't underestimate power of "small" tsunamis**
  - Some harbor personnel caught off guard by strong currents
  - Beach activity not as noticeable because of low tide
- For Advisories, keep boats at docks in harbors before arrival**
  - Yes... Small boats docked in areas protected from strong currents
  - No... Large boats can cause drag on and damage docks
- Don't take boats out of harbor during tsunami activity**
  - Harbor response boats struggled while patrolling harbors
  - Swamped boat at mouth of Mission Bay
- Don't try to reenter harbors too soon**
  - Strong currents make navigation difficult many locations
  - Boat owners must understand length of tsunami activity

## Additional Work:

Information from the March 11, 2011 event is still being compiled. One of the more interesting situations to be studied is the successful evacuation of most of the commercial fishing fleet out of Crescent City Harbor prior to the arrival of the tsunami. Evaluation of the experiences of these and other boaters will help understand their decision making process, how far they had to go offshore to be safe, and how others can learn from their experience.

The California tsunami program in cooperation with NOAA and FEMA has begun implementing a plan to increase awareness of tsunami generated hazards to the maritime community (both ships and harbor infrastructure) through the development of in-harbor hazard maps, offshore safety zones for boater evacuation, and associated guidance for harbors and marinas before, during and following tsunamis (Miller and others, 2011). An initial step in the program will be to calibrate current velocity modeling results against measured flow velocities associated with both the 2010 and 2011 tsunamis to identify the hazard and safety zones. The hope is that the maritime guidance and associated education and outreach program will help save lives and reduce exposure of damage to boats and harbor infrastructure.